Public-Private Partnerships for Space Capability Development

Driving Economic Growth and NASA's Mission

Interim Report

July 30, 2013

Study conducted in collaboration with the Office of Strategy Formulation and the Office of the Chief Technologist's Emerging Space Office

Introduction

- NASA has a legislative and executive mandate to work with the commercial sector
  - *A robust and competitive commercial space sector is vital to continued progress in space. The United States is committed to encouraging and facilitating the growth of a U.S. commercial space sector that supports U.S. needs, is globally competitive, and advances U.S. leadership in the generation of new markets and innovation-driven entrepreneurship*— **National Space Policy (2010)**
  - *To seek and encourage, to the maximum extent possible, the fullest commercial use of space* – **National Aeronautics and Space Act, 51 USC § 20112(a)(4)**

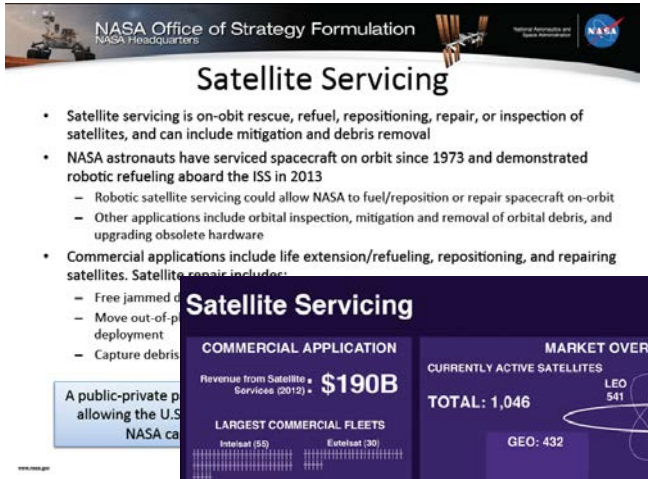
The purpose of this study is to provide economic intelligence on public-private partnership areas for space capability development that could meet NASA's mission objectives as well as strengthen US global competitiveness and promote the economic vitality of the nation

The Study

*The study focuses on **10 areas of space capability development** that show positive indicators of **private sector interest and investment**, new business formation, and alignment with NASA's objectives – thus **making them strong candidates for economic stimulation** with increased NASA partnerships and, potentially, resources*

- Identify and prioritize potential areas for engaging in public-private partnerships
  - Public-private partnership: agreement between NASA and industry that can be implemented with various instruments based on overall objective
- Provide a general summary of relevant NASA and commercial sector applications and interests in these areas
- Provide empirical data and economic intelligence on the market conditions, and supply and demand factors relevant to each area
- Use only publicly available information
- Study report is in-work; this presentation summarizes the report

Presentation Structure

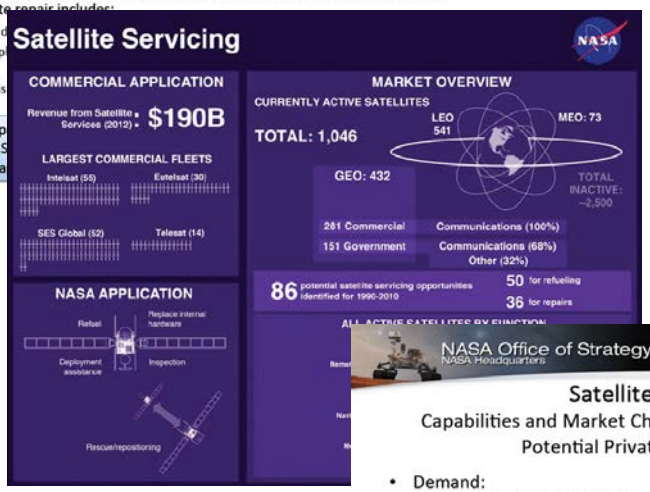

NASA Office of Strategy Formulation
NASA Headquarters

Satellite Servicing

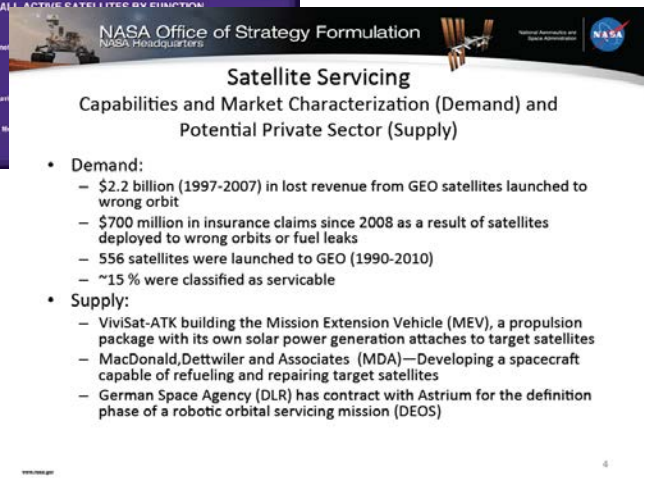
- Satellite servicing is on-obit rescue, refuel, repositioning, repair, or inspection of satellites, and can include mitigation and debris removal
- NASA astronauts have serviced spacecraft on orbit since 1973 and demonstrated robotic refueling aboard the ISS in 2013
  - Robotic satellite servicing could allow NASA to fuel/reposition or repair spacecraft on-orbit
  - Other applications include orbital inspection, mitigation and removal of orbital debris, and upgrading obsolete hardware
- Commercial applications include life extension/refueling, repositioning, and repairing satellites. Satellite repair includes:
  - Free jammed d
  - Move out-of-pl deployment
  - Capture debris

A public-private p allowing the U.S NASA ca

Provides definition of the area and a general summary of relevant NASA and commercial applications



Illustrates the market, including commercial applications, NASA applications, and the market overview (demand and supply summary)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Satellite Servicing

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand:
  - $2.2 billion (1997-2007) in lost revenue from GEO satellites launched to wrong orbit
  - $700 million in insurance claims since 2008 as a result of satellites deployed to wrong orbits or fuel leaks
  - 556 satellites were launched to GEO (1990-2010)
  - ~15 % were classified as servicable
- Supply:
  - ViviSat-ATK building the Mission Extension Vehicle (MEV), a propulsion package with its own solar power generation attaches to target satellites
  - MacDonald,Dettwiler and Associates (MDA)—Developing a spacecraft capable of refueling and repairing target satellites
  - German Space Agency (DLR) has contract with Astrium for the definition phase of a robotic orbital servicing mission (DEOS)

Provides empirical data and economic intelligence on market conditions, specifically, demand and supply data

Study Areas

1. Satellite Servicing
2. Interplanetary Small Satellites
3. Robotic Mining
4. Cargo Transportation Beyond LEO
5. Crew Transportation Beyond LEO
6. Microgravity Research for Biomedical Applications
7. Liquid Rocket Engines
8. Wireless Power
9. Space Communications
10. Earth Observation Data Visualization

Study Area Definitions

1. **Satellite Servicing:** On-orbit rescue, refueling, repositioning, repair, or inspection of satellites; can include mitigation and debris removal
2. **Interplanetary Small Satellites:** Spacecraft that conduct missions beyond LEO and have a mass of <500 kg
3. **Robotic Mining:** Extraction, processing, and transport of materials using autonomous or semi-autonomous equipment
4. **Cargo Transportation Beyond LEO:** Transport of goods, equipment, and resources
5. **Crew Transportation Beyond LEO:** Transport of crew, including astronauts and spaceflight participants
6. **Microgravity Research for Biomedical Applications:** Used by researchers in biomedical science as a tool for discovery of medically-important applications
7. **Liquid Rocket Engines:** Safe, reliable, cost effective engines
8. **Wireless Power:** Transmitting power over both short and long distances without wires
9. **Space Communications:** Technologies to transmit and relay data between satellites, vehicles in space, and assets on the ground
10. **Earth Observation Data Visualization:** Comprises the massive volume and diversity of data collected by Earth observation satellite systems

Satellite Servicing

- Satellite servicing is the on-orbit rescue, refueling, repositioning, repair, or inspection of satellites, and can include mitigation and debris removal
- NASA astronauts have serviced spacecraft on orbit since 1973 and demonstrated robotic refueling aboard the ISS in 2013
  - Robotic satellite servicing could allow NASA to fuel/reposition and repair spacecraft on-orbit
  - Other applications include orbital inspection, mitigation and removal of orbital debris, upgrading obsolete hardware, and capability applicability to exploration missions such as the asteroid retrieval mission
- Commercial applications include life extension/refueling, repositioning, and repairing satellites. Satellite repair includes:
  - Freeing jammed deployables (e.g., solar arrays and antennas)
  - Moving out-of-place thermal blankets and cables or cutting objects or cables restricting deployment

Public-private partnerships could help close the business case for U.S. companies, allowing the U.S. to become the world leader in satellite servicing while providing NASA capabilities for fixing or extending the life of its spacecraft

Satellite Servicing

COMMERCIAL APPLICATION

Revenue from Satellite Services (2012): **$190B**

LARGEST COMMERCIAL FLEETS

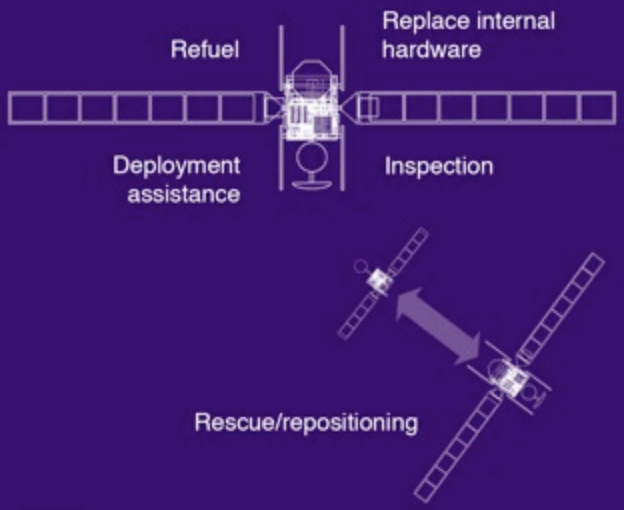
Intelsat (55)

Eutelsat (30)

SES Global (52)

Telesat (14)

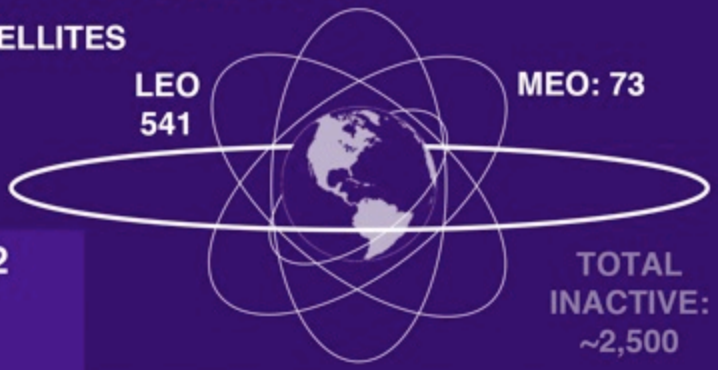
NASA APPLICATION



MARKET OVERVIEW

CURRENTLY ACTIVE SATELLITES

TOTAL: 1,046



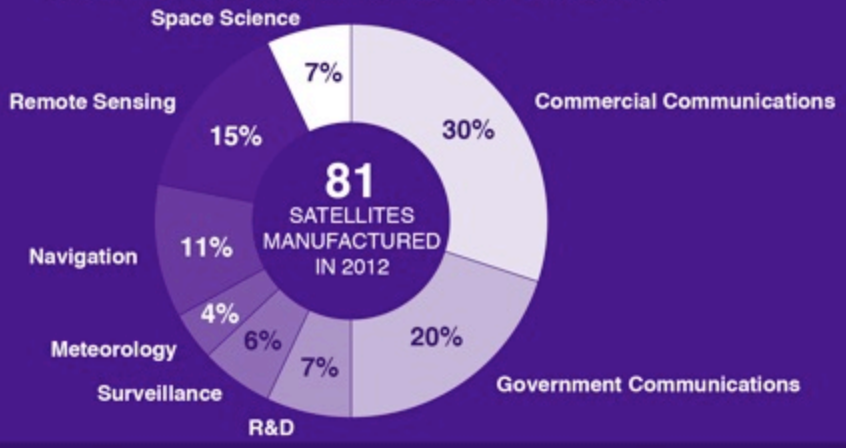
281 Commercial	Communications (100%)
151 Government	Communications (68%) Other (32%)

86 potential satellite servicing opportunities identified for 1990-2010

50 for refueling

36 for repairs

ALL ACTIVE SATELLITES BY FUNCTION



Satellite Servicing

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- Demand
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- Supply
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Interplanetary Small Satellites

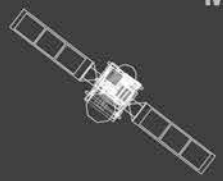
- Interplanetary small satellites are spacecraft that conduct missions beyond LEO and have a mass of <=500 kg
- NASA has used interplanetary small satellites since the 1960's to develop orbiters, probes, and landers designed to explore the solar system. Upcoming NASA interplanetary small satellite missions:
  - Lunar Atmosphere and Dust Environment Explorer (2013)
  - The InSight Mars lander (2016)
- Small satellites are becoming a larger component of the commercial satellite market, especially for remote sensing

Public-private partnerships in small satellites could help NASA explore the universe while pushing technology that would help improve the capability of U.S. satellites

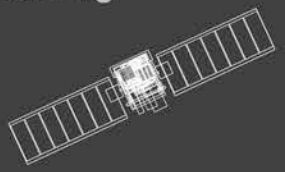
Interplanetary Small Satellites

COMMERCIAL APPLICATION

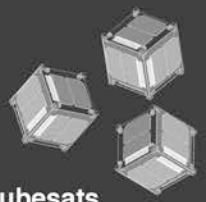
Masses ≤ 500 kg



Asset Tracking



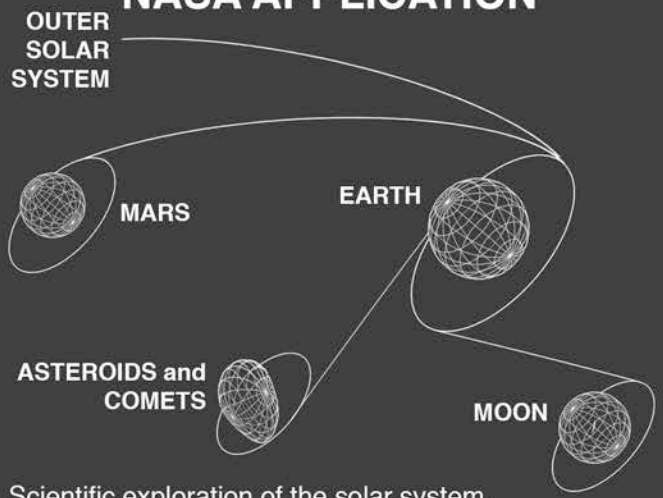
Remote Sensing



Cubesats

Orbital Telescopes

NASA APPLICATION

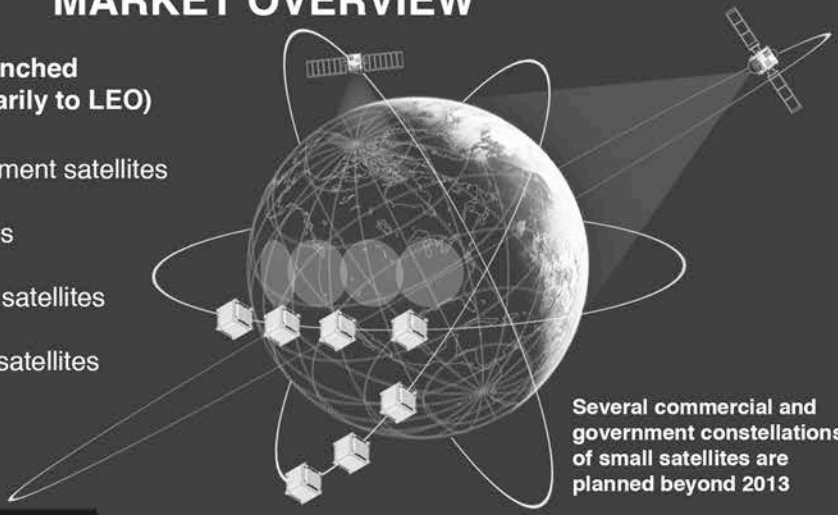


Scientific exploration of the solar system, including orbiting probes and landers

MARKET OVERVIEW

397 small satellites launched from 2003 to 2012 (primarily to LEO)

- **160** Test and development satellites
- **93** Scientific satellites
- **64** Communications satellites
- **61** Remote sensing satellites
- **19** Military satellites



Several commercial and government constellations of small satellites are planned beyond 2013

MAJOR SUPPLIERS

	Company	Payload Mass Limit
NANOSATS	Interorbital Systems	0.25 kg
	Northrop Grumman/Applied Minds	1 – 3 kg
	Clyde Space	1 kg
	GOMspace	1 kg
	NanoSatisFi	1 kg
	Pumpkin	1 kg
	Planet Labs	3 kg
	Andrews	10 kg, 40 kg
μ SATS	Boeing	10 kg, 180 kg, 500 to 1,000 kg (all in development)
	Surrey Satellite Technology (SSTL), EADS Astrium company	15 kg, 50 kg, 150 kg
	ATK	15 kg, 200 kg, 500 kg (in development)
	Microcosm	20 kg
SMALL SATS	Planetary Resources	100 kg (in development)
	Skybox Imaging	100 kg
	Sierra Nevada Corporation	100 kg (in development)
	Ball Aerospace	150 kg
	Northrop Grumman Corporation	200 – 500 kg
	Northrop Grumman/Sierra Nevada Corporation	458 kg
	Orbital Sciences Corp.	Up to 500 kg

Interplanetary Small Satellites

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - 397 small satellite (<= 500kg) have been launched over the past 10 years
    - 100 have been CubeSats
    - Civil governments and non-profits made up 70% of the demand
  - 350 CubeSats are expected to launch by 2020
  - $100 million raised by small satellite companies in venture capital and angel investment over the last few years years
- Supply
  - UK-based Surrey Satellite Technology, Ltd is the worldwide leader in building small satellites
  - At least 13 small satellite manufactures in the U.S.; most large U.S. satellite manufacturers also build small satellites
  - The DoD is investigating a variety of small satellite approaches

Robotic Mining

- Robotic mining is the extraction, processing, and transport of materials using autonomous or semi-autonomous equipment
- NASA plans to use robotic mining technologies for its long-duration human missions to asteroids, the moon, and Mars
- NASA issued an RFI to better understand U.S. industry's plans for robotic lunar landers
- Terrestrial mining companies are using robotic mining to access, process, and transport raw materials more safely and efficiently, and the use of robotic mining is expected to increase
- Five U.S.-based companies plan to develop automated technologies that could enable commercial mining of the Moon and asteroids

Partnerships among NASA, commercial space companies, and American mining technology companies could position the U.S. for economic growth and leadership in autonomous mining technologies

Robotic Mining

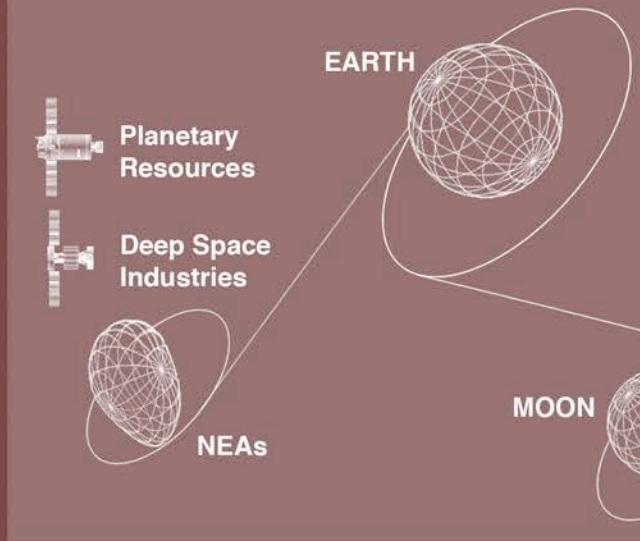
COMMERCIAL APPLICATION

Volatiles

Metals

Regolith and Rock

MARKET OVERVIEW



Planetary Resources

Deep Space Industries

TOTAL MINED FROM EARTH (in 2011):
Iron, ferro-alloy metals: 1.5 trillion tons
Non-ferrous metals: 79 billion tons
Precious metals: 27 million tons
Industrial materials: 715 billion tons
Mineral fuels: 14 trillion tons

Profits: $133B (2011)

Astrobotic Technology

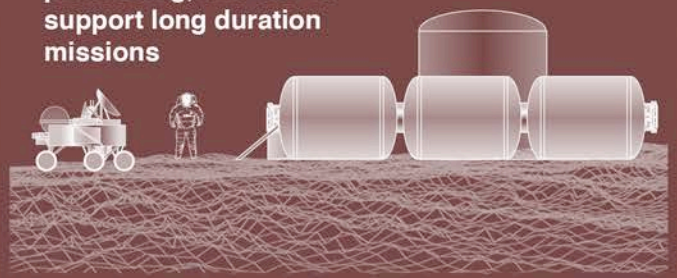
Shackleton Energy

Moon Express

NASA APPLICATION

Propellant transport

In situ extraction, processing, and use to support long duration missions



CURRENT AUTOMATED MINING EQUIPMENT SUPPLIERS

Caterpiller (USA)
Komatsu (Japan)
Sandvik (Sweden)
Atlas Copco (Sweden)
Hitachi Construction Machinery (Japan)
Volvo Construction Equipment (Sweden)

Northern Centre for Advanced Technology (Canada)

Carnegie Mellon University's Robotics Institute (USA)

Colorado School of Mines (USA)

POTENTIAL NON-TERRESTRIAL ROBOTIC MINING SUPPLIERS

Planetary Resources
Arkyd 100, Arkyd 200, and Arkyd 300

Astrobotic Technologies
Polaris, Red Rover

Shackleton Energy
Prospectors, lunar in situ processing propellant depots

Moon Express
Lander Test Vehicle

Deep Space Industries
Cubesat prospectors, MicroGravity Foundry series

Robotic Mining

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - Global mining industry is estimated to grow at a CAGR of 7.4% from 2012 to 2017, reaching $1.7 trillion in revenues
  - Global market for mining equipment is estimated to grow 8.5% annually through 2015, to $95 billion in revenues
  - Asia/Pacific region is the fastest growing market
  - Several large mining companies are already using autonomous or semi-autonomous equipment
- Supply
  - Companies in U.S., Japan, and Sweden are the primary manufacturers of automated terrestrial mining equipment
  - Canada's Northern Centre for Advanced Technology, Carnegie Mellon University's Robotics Institute, and the Colorado School of Mines are investing in robotic mining technology
  - Australian-U.K. firm, Rio Tinto, and university partners run four research centers dedicated to advancing mining robotics
  - Planetary Resources and Moon Express are the only companies that have secured significant investment for mining the moon and asteroids

Cargo Transportation Beyond LEO

- Cargo services beyond LEO include the transport of goods, equipment, and resources
- NASA requires cargo transportation for missions to near Earth asteroids, the moon, cis-lunar space, and Mars
- Potential commercial applications include transportation of mined material and equipment from the moon and asteroids; and equipment, material, consumables and waste for crewed expeditions
- NASA and Bigelow Aerospace signed an unfunded Space Act Agreement to identify new partnerships to "build the ability for humans to live and work in space through the expansion of exploration capabilities beyond low Earth orbit."

Partnerships to develop commercial transportation systems capable of sending cargo beyond LEO can provide NASA and other customers access to affordable cargo transportation while stimulating new commercial markets

Cargo Transportation Services Beyond Low Earth Orbit (LEO)

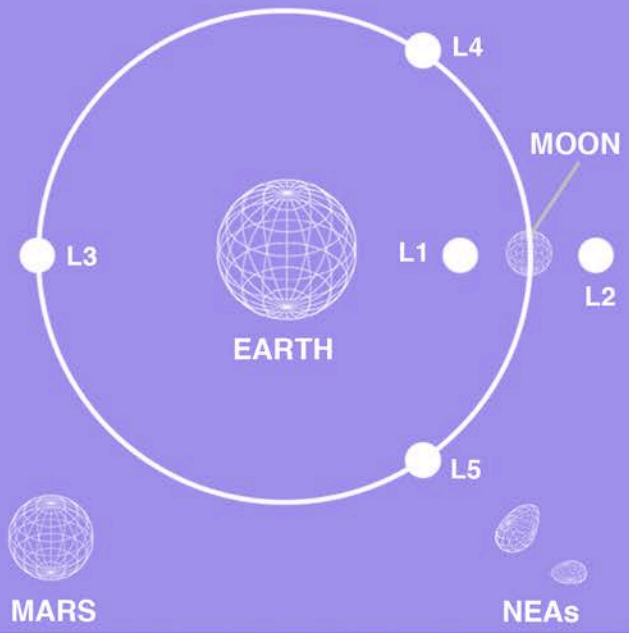
COMMERCIAL AND GOVERNMENT APPLICATION

Equipment

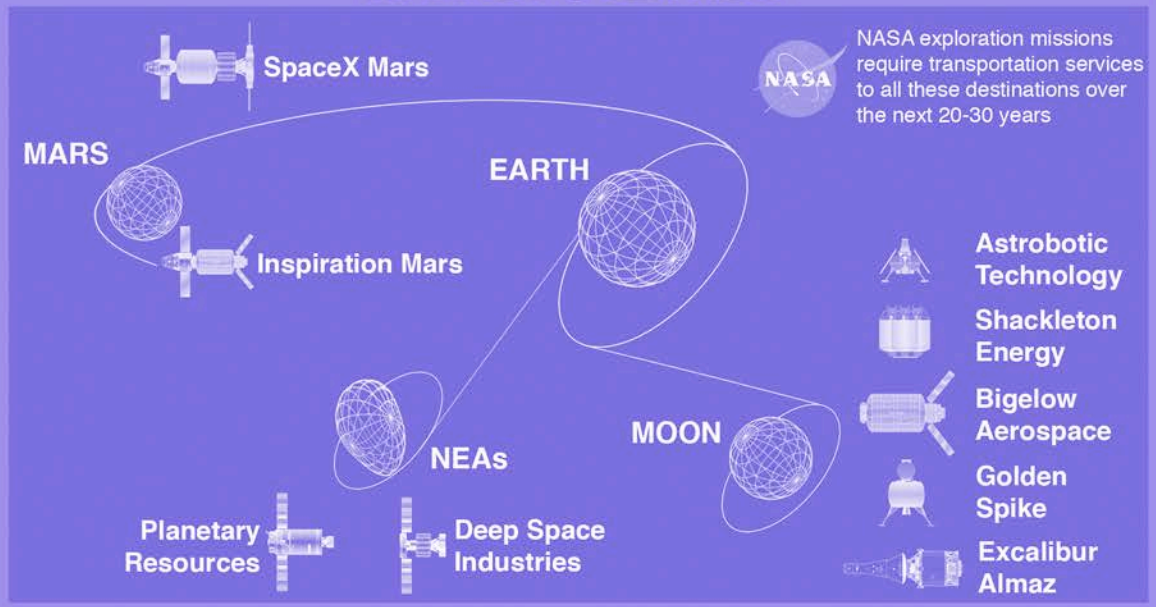
Volatiles


Resources

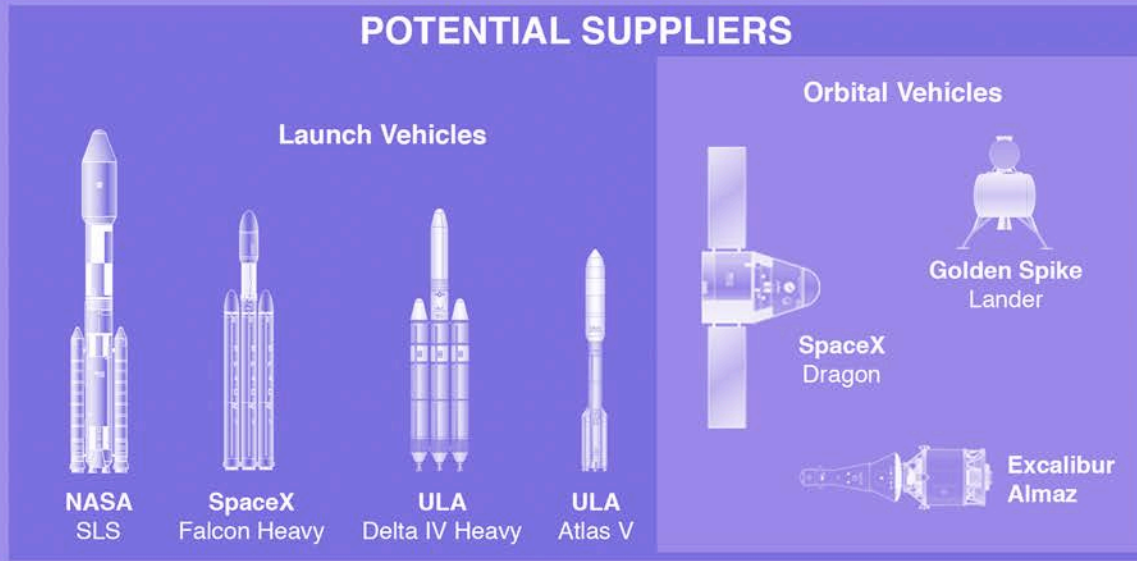

Supplies



MARKET OVERVIEW



POTENTIAL SUPPLIERS



Cargo Transportation Beyond LEO

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - 10 private companies and nonprofits are planning activities beyond LEO that will require cargo services
  - Bigelow Aerospace, SpaceX, and Planetary Resources have the most mature plans and private investment
    - Robert Bigelow has pledge to invest $500 million developing inflatable modules
    - SpaceX has $200 million in private investment ($100 million from Elon Musk)
    - Planetary Resources raised over $1 million through crowd-funding
- Supply
  - There are currently no cargo transportation spacecraft capable of going beyond LEO in service; although capability in development
  - Modified Dragon, Excalibur Almaz, and Golden Spike's Northrop Grumman designed vehicle are all planned to carry cargo beyond LEO
  - No other country has invested significant resources in cargo capability beyond LEO

Crew Transportation Beyond LEO

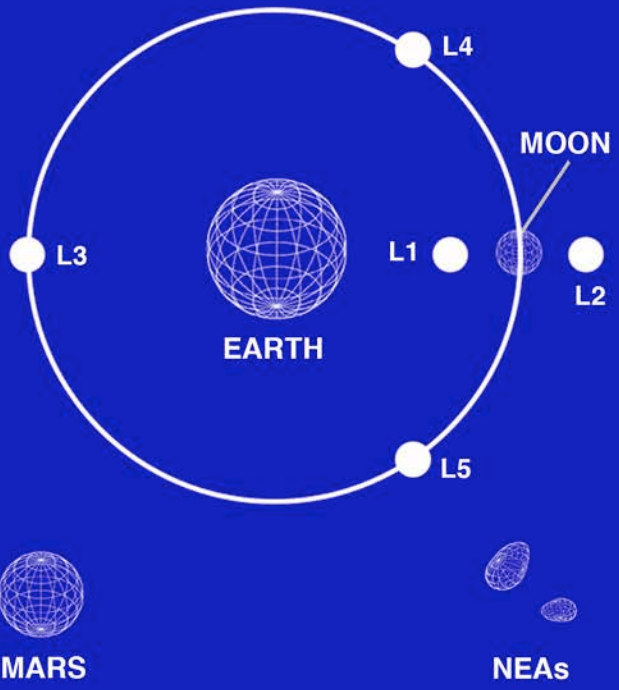
- Both NASA and American private sector interests will ultimately require crew transportation beyond LEO
- NASA requires crew transportation for human exploration missions to near Earth asteroids, the moon, cis-lunar space, and Mars
- Commercial companies are planning to transport humans to the moon, Mars, and near Earth asteroids (NEAs). Ventures range from establishing outposts to mining operations to tourist fly-bys

Partnerships to develop commercial transportation systems capable of sending crew beyond LEO can provide NASA and other customers access to affordable crew transportation while stimulating new commercial markets

Crew Transportation Services Beyond Low Earth Orbit (LEO)

COMMERCIAL AND GOVERNMENT APPLICATION

NASA plans to send humans beyond LEO using the SLS and Orion Multi-Purpose Crew Vehicle. Meanwhile, companies are planning to establish outposts mining operations, tourist fly-bys and expeditions to the Moon, Lagrangian Libration Points, Near Earth Asteroids, and Mars during the next two decades.



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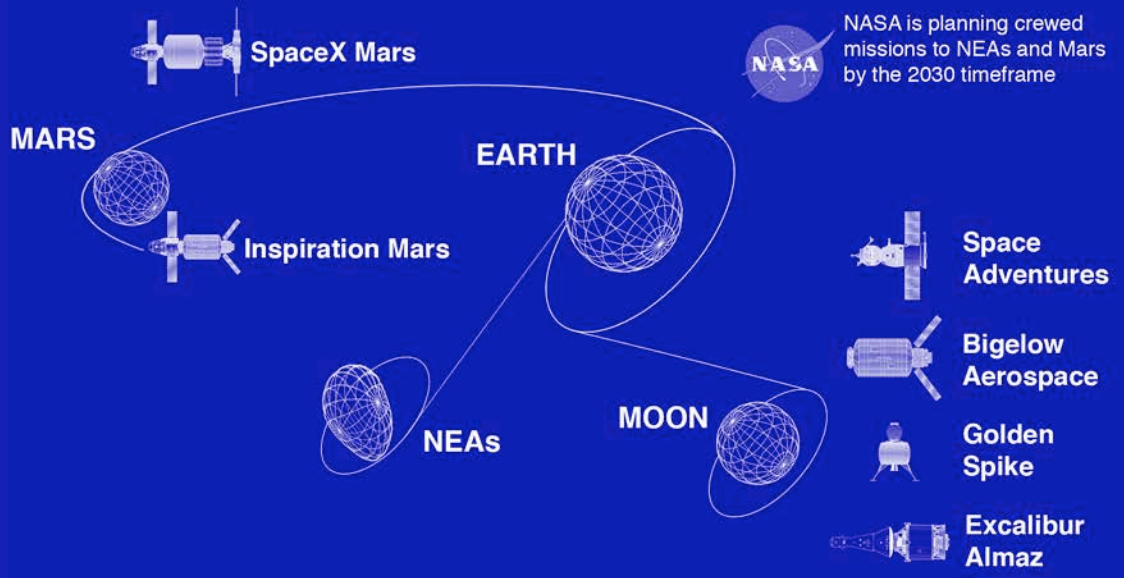
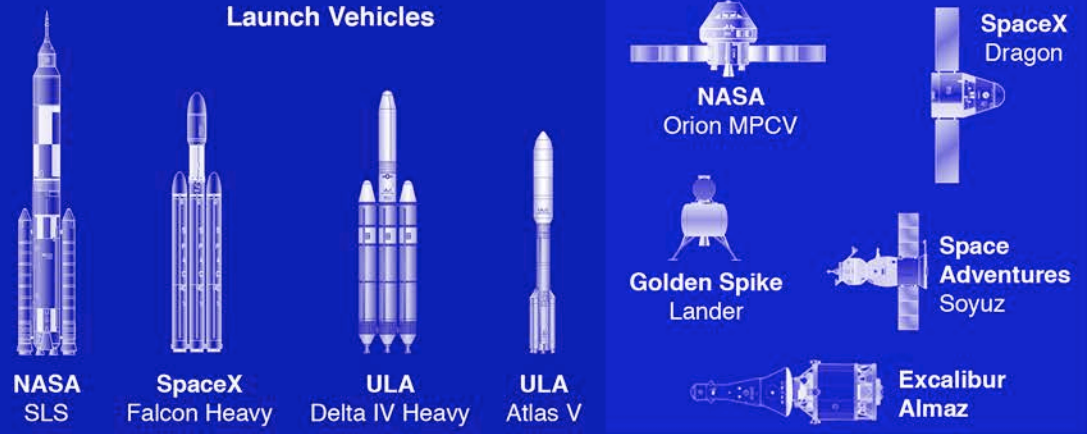


POTENTIAL SUPPLIERS



Crew Transportation Beyond LEO

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - Expeditions: Space Adventures and Excalibur Almaz are selling fly-bys of the Moon for $100 million to $150 million a seat; Inspiration Mars is planning a single trip to Mars in 2018 with greater than $100 million investment pledged
  - Outposts and colonies: SpaceX plans to send people to Mars for $500K a seat in the 2030 timeframe; a Dutch company, Mars One, is signing up people to compete for a one-way trip to Mars (~1000 people have signed up to date)
  - Resources: Golden Spike is planning human missions for 2 people to the moon for $750 million to $1.5 billion per mission
- Supply
  - There are no crew transportation spacecraft capable of going beyond LEO currently in service although capability in development
  - Orion, modified Dragon, Excalibur Almaz's TKS, Space Adventures' Russian Soyuz, and Golden Spike's Northrop Grumman-designed vehicle are all planned to carry humans beyond LEO
  - In 2010, China announced plans to send humans to the moon by 2025, and have already demonstrated human space flight capability
  - No other country has invested significant resources in human capability beyond LEO

Microgravity Research for Biomedical Applications

- Microgravity is used by researchers in biomedical science as a tool for discovery of medically-important applications
- NASA research focuses on allowing humans to live and work in space
  - Human exposure to microgravity is associated with bone loss, muscle atrophy, decreased cellular immune response, impaired wound healing, and neurological alterations
  - NASA's research can provide insight that leads to new therapeutics to treat these and similar conditions, many of which are also prevalent in our aging population
- Companies are interested in conducting space-based microgravity research
  - Drugs to treat diseases affecting the elderly, cancer, and infectious diseases
  - Tissue engineering and regenerative medicine using space-grown stem cells
  - Protein crystallization for drug discovery and development

Biomedical research in the ISS microgravity laboratory environment offers an unparalleled, sustained opportunity for discovery in a variety of medically-important applications leading to social and economic benefits

Microgravity Research for Biomedical Applications

COMMERCIAL APPLICATION

Drugs for diseases that afflict the elderly

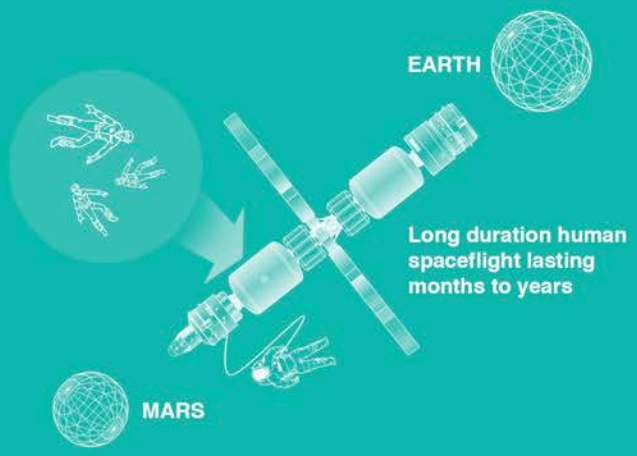
Drugs for infectious diseases

Drugs for oncology

Stem cell research

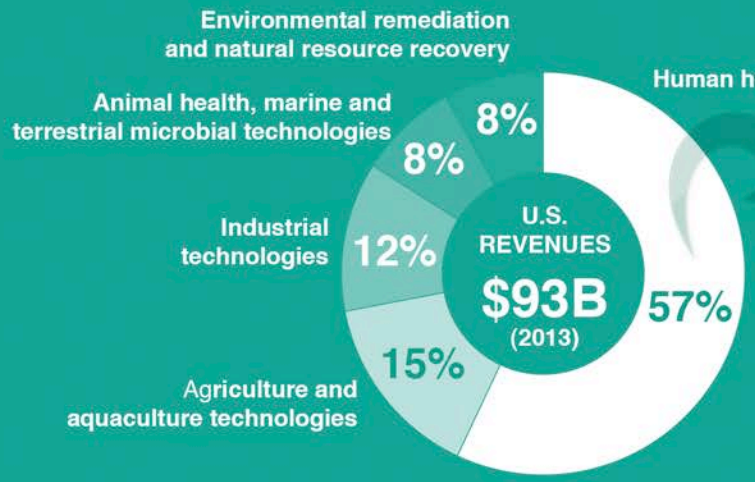
Protein crystallization

NASA APPLICATION



MARKET OVERVIEW

U.S. BIOTECHNOLOGY INDUSTRY



$23B 43% Oncology drugs

$5B 10% Infectious diseases drugs

POTENTIAL SUPPLIERS (2013-2020)

Suborbital

- Blue Origin New Shepard
- XCOR Lynx
- Virgin Galactic SS2
- Armadillo STIG
- UP Aerospace SpaceLoft
- Masten Xaero
- ZERO-G

Orbital

- Boeing CST-100
- NASA ISS
- SpaceX DragonLab
- Blue Origin Space Vehicle
- SNC Dream Chaser
- Orbital Sciences Cygnus
- Bigelow BA 330

Microgravity Research Facilitators

- CASIS
- NanoRacks

MICROGRAVITY RESEARCH

Demand for drugs to treat diseases that mimic the health effects of space flight is high and expected to grow as population over 65 increases

Microgravity Research for Biomedical Applications

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - $93 billion U.S. biotechnology industry has over 2,000 companies; industry expected to grow as population ages; 57% of the industry is biomedical technologies
  - Large biotech companies Amgen and Merck as well as J. Craig Venter Institute are conducting research on ISS
  - ~30% of the best-selling 100 drugs are for degenerative diseases like arthritis, cancer, and osteoporosis
- Supply
  - NASA ISS Laboratory
  - NASA-developed rotating wall bioreactor used for initial testing
  - Suborbital reusable vehicles such as XCOR's Lynx or Virgin Galactic's SpaceShipTwo provide 4-5 minutes of microgravity
  - SpaceX's Dragon can return samples to Earth, Orbital's Cygnus can stay in orbit up to 2 years
  - Bigelow Aerospace is planning inflatable modules for research and tourism
  - NanoRacks and CASIS are microgravity research facilitators

Liquid Rocket Engines for Launch Vehicles

- Liquid rocket engines (LREs) are part of the primary propulsion system for launch vehicles
- NASA's Commercial Orbital Transportation Services (COTS) program enabled the development of new space transportation system
  - Established the U.S. as a cost-effective provider of global launch services
  - Helped gain back launch vehicle market share lost to foreign providers
- LREs are currently used to power the Atlas V (RD-180), Delta IV (RS-68A), SpaceX Falcon vehicles (Merlin), and Orbital Science's Antares vehicle (AJ26)
- U.S. companies currently developing simpler, less expensive LREs

Facilitating the development of safe, reliable, cost effective engines for government and commercial customers could further position the U.S. to gain back launch vehicle market share lost during the past decade

Liquid Rocket Engines for Launch Vehicles

COMMERCIAL APPLICATION

EXISTING U.S. LAUNCH VEHICLES USING LRE

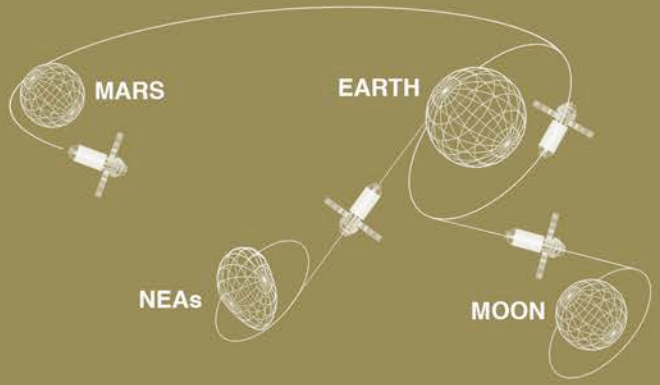
Atlas V
1st stage: RD-180 (legacy)
2nd stage: RL10A-4-2 (legacy)

Delta IV
1st stage: RS-68A (new)
2nd stage: RL10B-2 (legacy)

Falcon 9
1st stage: 9 Merlin 1D (new)
2nd stage: 1 Merlin 1D (new)

Antares
1st stage: AJ26 (legacy)

NASA APPLICATION



New, more powerful and efficient LREs enable NASA to pursue human missions beyond LEO and to continue robotic missions to the Moon, Mars, and other destinations throughout the solar system.

MARKET OVERVIEW

COMMERCIAL ORBITAL LAUNCH MARKET SHARE BY NUMBER OF LAUNCHES AND REVENUES

Beginning in 2013, the U.S. is expected to increase its market share from an annual average of 13% to 28-32% in 2013. SpaceX's commercial satellite contracts and flights to the ISS are driving increase.

Aerojet Rocketdyne	RS-68A J-2X AJ26 RS-25 RD-180 (RD AMROSS) RL10
SpaceX	Merlin 1D

Other major U.S. LRE development efforts

Armadillo Aerospace (small, restartable)
Blue Origin (BE-3)
Masten Space Systems (small, restartable)
ORBITEC (VR-3A)

Liquid Rocket Engines

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - $2.5 to $3 billion annual revenue for the commercial launch industry with an average of 19 launches a year
  - In the next 10 years the commercial launch market is expected to grow to an annual average of 31 launches; increase primarily driven by telecom replacements and commercial ISS flights
  - The U.S. was losing market share for commercial launches, with no U.S. commercial launches in 2011
  - In 2012, the U.S. regained some market share with SpaceX's ISS commercial flights
- Supply
  - U.S. manufacturers of LREs are Aerojet Rocketdyne and SpaceX
  - Four companies are in various stages of development of LREs; some are smaller engines for suborbital vehicles
  - Russia is the other major provider of LREs
    - RD Amross, a joint U.S.-Russian company, provides the RD-180 for the Atlas V
    - India's GSLV and Korea's Naro-1 use Russian LREs
  - French company Snecma makes the LREs for Europe's Ariane V and Vega vehicles

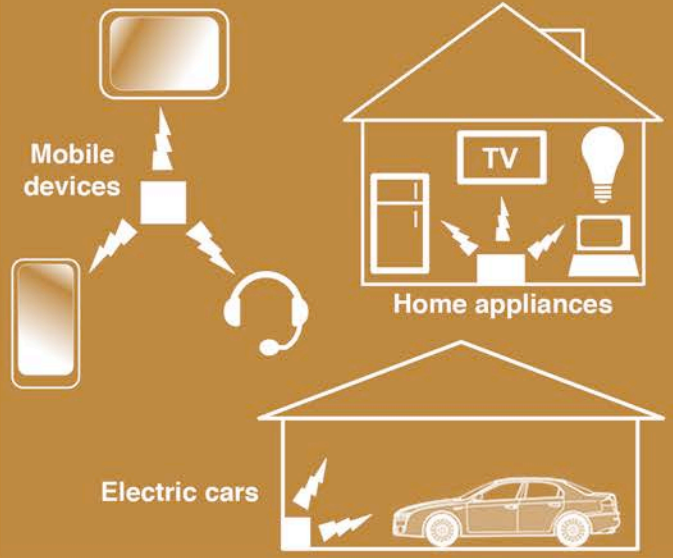
Wireless Power

- Wireless power is the capability to transmit power over both short and long distances without wires
- NASA's use for wireless power includes powering rovers in dark craters, propelling aerospace vehicles, or beaming energy to a launch system
- The most ambitious commercial application of wireless power beaming is to provide power to Earth's power grid from space
- The military is interested in power beaming from ground lasers to unmanned aerial vehicles
- Most widely used form of commercial wireless power is near-field electrical device and vehicle charging

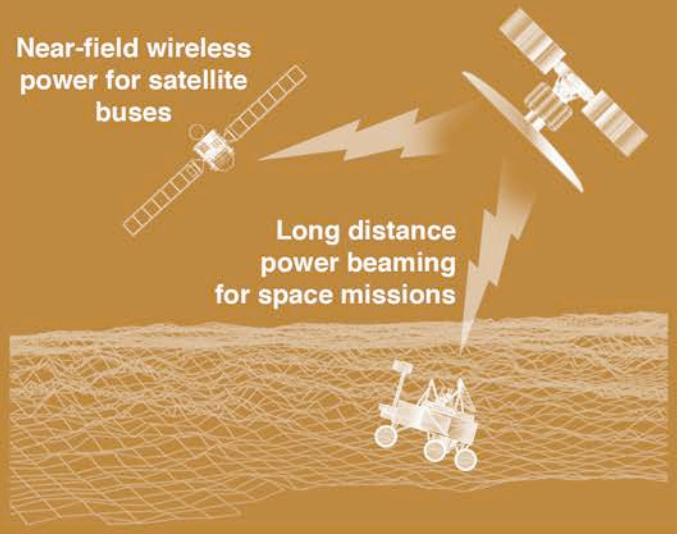
Public-private partnerships could help advance U.S. competitiveness in the growing wireless power market while helping enable NASA's exploration missions

Wireless Power

COMMERCIAL APPLICATION

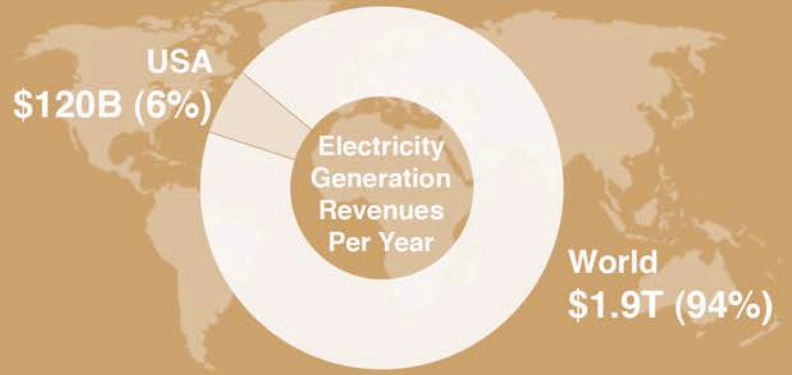


NASA APPLICATION



MARKET OVERVIEW

World energy comsumption:
20 trillion kW hours per year



Major Wireless Power Market Today

Consumer electronics revenue per year
$170B

Wireless charging industry
$1B

DEMAND PROJECTIONS

From **3.8T** kW hours per year

To **4.9T** kW hours per year by 2040

$6B

2020 wireless charging industry revenue projection

ONGOING RESEACH

WIRELESS CHARGING OF ELECTRIC CARS

BMW with Siemens
Toyota, Mitsubishi, and Audi with Witricity and Delphi
Renault and Delta Motorsports with Qualcomm
Evatran with SPX Service Solutions, Google, and Hertz

WIRELESS POWER BEAMING FROM SPACE

Centers of research:
USA
Russia
China
Japan

WIRELESS POWER BEAMING TO UAVs

World UAV industry was $6.6B in 2012; Industry projected to be $87B by 2018

Wireless Power

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - Demand for electricity is expected to double between 2000 and 2030
  - UAVs are predicted to grow at an annual rate of 12% over the next 5 years, generating $86.5 billion in revenues
  - The wireless charging market is expected to grow from $1 billion to $6 billion by 2020
- Supply
  - In a 2012 conference, Russian and Chinese government officials presented concept papers on delivering power from space; Japanese government officials presented plans for a 2014 small-scale test
  - LaserMotive has demonstrated powering a UAV via power beaming
  - A number of wireless charging technologies are being developed by industry, including plug-in vehicle providers partnering with wireless charging companies
  - Korea's Advanced Institute of Science and Technology and Utah State University both demonstrated wireless charging of buses

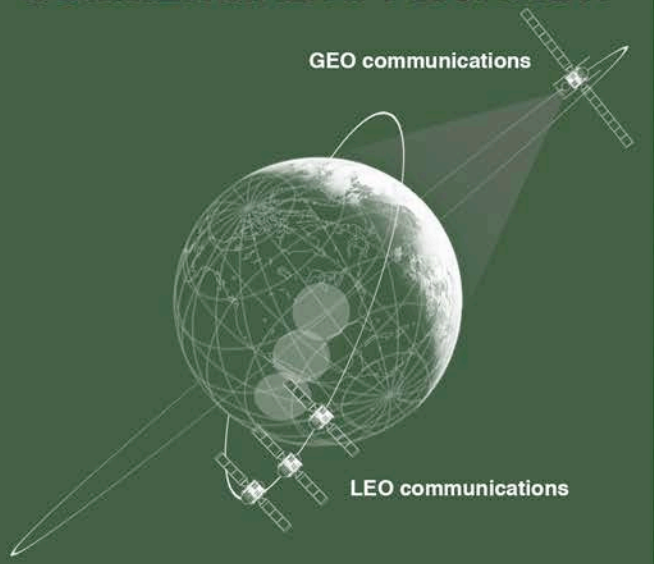
Space Communications

- Space communication technologies transmit and relay data between satellites, vehicles in space, and assets on the ground
- NASA uses space communication technologies to transmit and relay data between satellites, vehicles in space, and assets on the ground for GEO, LEO, cis-lunar, and deep space activities
- Commercial telecommunications companies use space communication technologies for telephone, television, data (including Internet), and radio signals

Public-private partnerships with the U.S. telecommunications industry could increase U.S. market share in largest commercial space market while increasing NASA's options for space communications

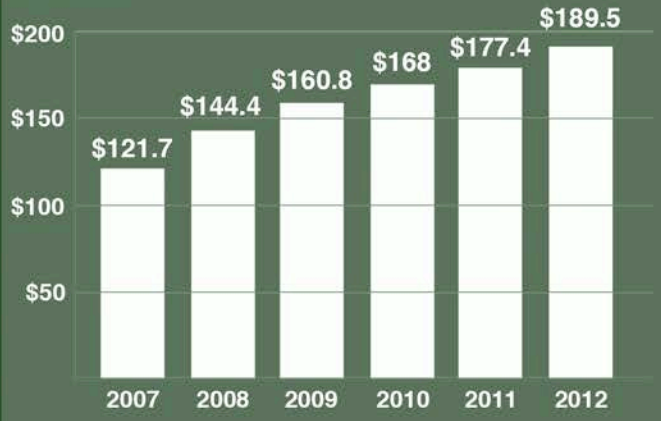
Space Communications

COMMERCIAL APPLICATION



MARKET OVERVIEW

Global Satellite Industry Revenues
($ Billions)



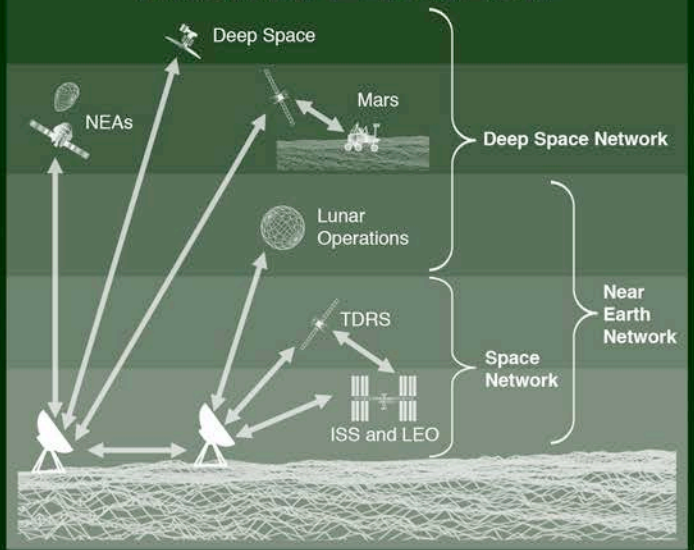
Satellite Services
Television, radio, broadband, fixed, mobile, remote sensing
$113.5B

Satellite Manufacturing
$14.6B

Launch Services
$6.5B

Ground Equipment
GPS devices, satellite TV dishes, VSATs, network gateways
$54.8B

NASA APPLICATION



DEMAND

1.4 terabits per second
Demand for bandwidth (2002)

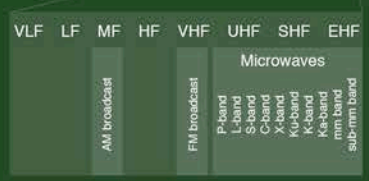
1,000 terabits per second
Demand for bandwidth (2020)

Global growth of satellite services from 2011 to 2012

7%

RESEARCH AND DEVELOPMENT

Optical and X-ray communication technologies could increase throughput by 10 to 100 times over radio



NASA
DoD
European Space Agency
DLR

Organizations currently investigating optical (laser) communications systems.

Space Communications

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - Telecommunications is a $4.9 trillion industry; satellite services is $114 billion
  - Global satellite manufacturing revenues in 2012 were $14.6 billion; the U.S. accounted for 60% of revenues
  - In 2002, telecom satellites provided 1.4 terabits per second; expected to increase to 1,000 terabits per second by 2020
  - ~18 commercial telecommunications satellites are expected to be launched annually. No significant increase in launches are expected. Increased bandwidth is expected to come from more capable satellites
  - Demand for bandwidth is expected to grow
- Supply
  - ~50 commercial services satellite operators. The big 4, Intelsat, Eutelsat, Telesat, and SES hold about 40% of the market
  - New market entrants include O3b (backed by SES, Google and HSBC and raised $1.2 billion in financing to build its satellites) and LightSquared (in bankruptcy restructuring, received $2.9 billion in assets from Harbinger Capital Partners and more than $2.3 billion in debt and equity financing)
  - New technology—laser communication, investments primarily from U.S. and European governments (NASA, DoD, ESA, DLR) and U.S. industry including Planetary Resources and satellite manufacturers

Earth Observation Data Visualization

- There is a massive volume and diversity of data collected by Earth Observation satellite systems – a prime example of "big data". Understanding and using this data requires innovative approaches to data analysis and visualization.
- NASA has been at the forefront of visualization projects through partnerships like Cisco (Planetary Skin) and Google (Google Earth)
- NASA uses Earth observation data to enable understanding of the Earth as a system
  - NASA currently collects 1.73 gigabytes (Gb) of data per hour, and new missions could increase this to 24 terabytes (Tb) per day
  - NASA shares all of its Earth observation data with public. It is used extensively for scientific, civil, humanitarian, and commercial applications
  - Nearly 3 million scenes from NASA's Landsat were downloaded in 2011, over 625 million downloads of EOSDIS products in 2012
- The diversity of Earth observation data fused with data from other sources is creating an explosion of commercial applications; monitoring oil and gas pipelines, managing natural resources, monitoring crops and pollution, identifying sites for mining, predicting and assessing the effects of natural disasters, obtaining competitive intelligence, and providing decision support

Public-private partnerships that combine NASA's unique expertise in Earth science data collection, processing, and visualization with capabilities of U.S. data analysis companies could improve NASA's mission to study planet Earth and facilitate commercial applications

Earth Observation Data Visualization

COMMERCIAL APPLICATION

Mapping
Mining
Utilities
Agriculture
Forestry
Oil and Gas
Maritime
Real Estate
Humanitarian

MARKET OVERVIEW

RAW IMAGE ACQUISITION

$9.1B 2012 estimated total worldwide revenue

Satellites **$3.6B**

Aerial **$2.6B**

Terrestrial and aquatic: **$2.9B**

GEOGRAPHIC INFORMATION SYSTEMS

$5B
2012 estimated total worldwide revenue

Value added data

Raw image

$10.6B by 2015

Climate change annual data volume projected to be over 150 petabytes by 2030

NASA APPLICATION

NASA focuses primarily on Earth science missions

NASA developed systems to manage, process, store, archive, distribute, and visualize GIS products, partnering with Cray and Cisco, among others

U.S. SATELLITE REMOTE SENSING COMPANIES

DigitalGlobe
QuickBird
IKONOS
GeoEye-1
WorldView-1
WorldView-2
WorldView-3 (2014)

PlanetIQ
12-24 satellites
(launch date TBD)

Planet Labs
Dove-1
Dove-2
Dove-3 (2013)
Dove-4 (2013)
Flock-1 (28 satellites) (2014)

SkyBox Imaging
SkySat-1 (2013)
SkySat-2 (2013)

Southern Stars
SkyCube (2013)

Earth Observation Data Visualization

Capabilities and Market Characterization (Demand) and Potential Private Sector (Supply)

- Demand
  - The geographic information system (GIS) market is growing at an annual rate of almost 35%. Global GIS market expected to reach $10.6 billion by 2015
  - Space-based remote sensing products are expected to grow to $5 billion by 2017 at a CAGR of 6.8%
  - Satellite climate change data is expected to reach over 150 petabytes in 2030
  - Demand for additional processing capabilities and services is expected to grow in the future to meet the need for climate data records
- Supply
  - GIS companies in U.S. include: ESRI, Intergraph, MapInfo, Global Information Systems, Inc., New Century Software, TerraGo Technologies and SharedGeo
  - Data analytics companies interested in Earth Observation products include: IBM, Cray, Cisco (Planetary Skin), and Google
  - U.S. commercial satellite Earth observation companies include Digital Globe and Planet Labs; other providers who have not yet launched satellites include PlanetiQ, Southern Stars, and Skybox
  - Europe's EADS Astrium is an international provider of Earth observation data and provides data from SPOT Image, InfoTerro, DMCii (Surrey Satellite)
  - NASA, NOAA, and DoD operate dozens of Earth observation satellites

Summary

By leveraging **public-private partnerships** as a regular part of the agency's approach to **space capability development**, NASA's programs can be a fundamental driver of **U.S. economic growth in the 21st century**

Recommendations

1. Integrate economic analysis and market evaluation into Agency strategic decision-making and acquisition process for program formulation

2. Engage in public-private partnerships in those areas that have attracted private capital, which have technical merit, and contribute to achieving NASA's overall Mission and are in the national interest

3. Develop a strategy and architecture for space exploration that includes public-private partnerships

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